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In re Patent Application of:
Pierre Bernard et al.

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For: A METHOD FOR MANUFACTURING A FBG HAVING IMPROVED PERFORMANCES AND AN ANNEALING-TRIMMING APPARATUS FOR MAKING THE SAME

Examiner: Not Yet Assigned

CLAIM FOR PRIORITY AND SUBMISSION OF DOCUMENTS

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Applicant hereby claims priority under 35 U.S.C. 119 based on the following prior foreign application filed in the following foreign country on the date indicated:

Country	Application No.	Date
Canada	2,418,888	February 14, 2003

In support of this claim, a certified copy of the said original foreign application is filed herewith.

Dated: March 5, 2004

Respectfully submitted,

By

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Canadian Patent Office

Certification

This is to certify that the documents attached hereto and identified below are true copies of the documents on file in the Patent Office.

Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,418,888**, on February 14, 2003, by **TERAXION INC.**, assignee of Pierre Bernard, Nathalie Grégoire and Ghislain Lafrance, for "A Method and Apparatus to Improve Chirped Fiber Bragg Grating Gain Flattening Filters".

Agent certificateur/Certifying Officer

December 12, 2003

Date

Canada

(CIPO 68)
04-09-02

OPIC CIPO

A METHOD AND APPARATUS TO IMPROVE CHIRPED FIBER BRAGG GRATING GAIN FLATTENING FILTERS

FIELD OF THE INVENTION

The present invention generally relates to a method and an apparatus for improving the fabrication of complex fiber Bragg grating (FBG) filters. More particularly, The invention concerns a method and apparatus for quickly modifying the spectral response curve of FBG filters in order to precisely match a pre-defined target spectra, preferably but not exclusively the inverse gain profile of an Er doped fiber amplifier (EDFA).

BACKGROUND OF THE INVENTION

FBGs and chirped FBGs are widely used technologies to fabricate complex filters. Gain flattening filters for EDFAs are but one example. Gain flatness of optical amplifiers over the communication bandwidth is a key requirement of high performance optical Wavelength Division Multiplexing (WDM) communication systems. Usually, a gain flattening filter with a spectral response matching the inverse gain profile is incorporated within the amplifier to flatten its gain.

Several gain flattening filter technologies can be used to perform the gain equalization, thin film filters and chirped FBGs being the most widely used (1). A key metric of performance for gain flattening filters is the insertion loss error function (ILEF): the difference between the measured attenuation of the filter and the target spectra. The target spectra is specific to each amplifier design and is closely related to the inverse gain curve. Because amplifiers are often cascaded along a link, the cumulative effect of the error function of the individual filters is also of importance. Individual filter ILEF smaller than or equal to ±0.1 dB for the full operating temperature and wavelength range of a system are often required, and the ILEF must be as random as possible to avoid the additive effect of systematic errors. In the case of thin film filters-gain flattening filter, the manufacturing process is such that all gain flattening filters have very similar error

functions of the order of ±0.25 dB and these systematic errors can add up to unacceptable levels.

The chirped fiber Bragg grating is an attractive technology to produce very low error gain flattening filters. Although several manufacturing approaches are possible, gain flattening filters are typically inscribed in photosensitive fibers using UV light and a chirped phase mask to create an interfering pattern with linearly changing period along the grating. The amplitude of the resulting index modulation can also be shaped by controlling the intensity of the UV-light along the phase-mask. This shaping and trimming process at the UV-writing station is required to obtain low ILEF.

UV-induced defects are responsible for the grating formation but these defect sites are not thermodynamically stable and the change in refractive index can be reversed. This is why gratings are then subjected to a stabilization process, which is a controlled temperature anneal. This annealing progressively removes the most unstable defect sites and the final grating is stable within the system tolerances for the intended grating lifetime. Of course, the annealing step reduces the refractive index modulation and consequently, the grating must be written stronger in order to hit the post-annealing target. This manufacturing process is quite adequate for ILEF of the order of ±0.25 dB. However, imperfections in the phase mask, mechanical and laser instabilities make it very difficult to obtain ILEF smaller than ±0.15 dB. In those cases, a lengthy manual UV-trimming process is often required. Even then, the subsequent temperature annealing process can slightly distort the final spectral shape and the resulting production yield is low. Finally, because the UV-trimming process is operator dependent, it often leads to small but noticeable systematic errors in the ILEF. Very similar process steps apply to other types of complex filters based on FBGs and chirped FBGs. In those cases, the metric can be something other than the ILEF but the general method and apparatus described in this invention would apply equally.

OBJECTS AND SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method and apparatus allowing a more precise tailoring of the characteristic spectra of a complex FBG filter than for prior art manufacturing techniques.

It is a preferable object of the invention to manufacture gain flattening filters having an ILEF smaller than ±0.15 dB.

In accordance with an aspect of the present invention, the trimming and annealing steps are combined into a single process in order to efficiently fabricate complex FBG filters with improved performance. In the case of gain flattening filters, this lead to filters with very low ILEF. More particularly, the present invention automatically generates a controlled temperature profile along the FBG in order to precisely control the annealing process until the FBG spectral curve equals the target curve.

Advantageously, the present invention makes possible the creation of any desired temperature profile along the length of the FBG. It allows to precisely locate the FBG in space, and to affect local correction to the FBG spectral curve without affecting nearby points. The method and apparatus of the present invention also make it possible to estimate the necessary time and temperature to affect the required correction and end-of-life performance of the FBG after final processing, and estimate and take into account cladding mode losses of the FBG. Systematic errors between the final spectral curve and the target curve on a cascaded series of FBGs are advantageously reduced.

Other features and advantages of the present invention will be better understood upon reading of preferred embodiments thereof with reference to the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph (left) representing isochronal annealing curves for a typical CFBG-GFF. At any given wavelength, the behavior is well represented by a master curve (right).

FIG. 2 is a flow chart of the algorithm used in correcting the gain flattening filter.

FIG. 3 is a schematic of the annealing-trimming station.

FIG. 4 (top) shows the applied laser fluence (temperature) profile. Bottom curves are the measured and predicted changes in the GFF transmission spectra.

FIG. 5 shows the evolution of the error function from start (bottom trace) to finish (top trace). Each trace represent a 10 seconds profiled annealing.

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

The present invention concerns a method and apparatus where the requirements at the UV-writing station are considerably relaxed when compared to prior art techniques. No UV-trimming is necessary and it is sufficient, in the case of gain flattening filters, that the FBG attenuation curve be everywhere superior to the target attenuation curve, with provision for the annealing step. Then, instead of a uniform annealing, the next step involves a controlled annealing along the grating length in order to precisely match the target spectra. This requires both a good understanding of the ageing/annealing process along the FBG and a mean to precisely control it.

The ageing curve or master curve approach to decay analysis has proven to be a useful model to understand and predict the change in refractive index modulation (Δn) versus time and temperature (3). In this model, the change in refractive index modulation is a function of the ageing parameter, or equivalently the demarcation energy E_d:

$$(\Delta n)_{final} = (\Delta n)_{initial} + s\,(E_d^{final} - E_d^{initial}) \qquad (1)$$

where s is the slope parameter related to the defects energy distribution and E_d is a function of temperature (T) and time (t):

$$E_d = k_{Boltzman} \cdot T \ln(\nu_0 t) \qquad (2)$$

where v_0 is the frequency factor, a constant for a given fiber type and UV-writing process. This model was extended to the case where the slope factor s can change along the grating, or equivalently, as a function of the wavelength in the filter spectra ($s(\lambda)$) of a chirped FBG. The validity of this assumption is supported by its success in predicting the change in refractive index modulation with temperature and time.

FIG. 1 illustrates how it is applied to a specific gain flattening filter. The gain flattening filter was submitted to a series of isochronal annealing steps of increasing temperature. The master curve for a specific wavelength (vertical line on the left-hand graph) is also shown on the right-hand graph. The results fit very well with equation 1. In practice, the calculated slope can vary along the length of the grating. Once $s(\lambda)$ is known, it is possible to calculate the required annealing conditions that will reduce the refractive index modulation by a given amount. In this fashion, the transmission spectra can be matched to any lower-loss target.

Trimming the gain flattening filter spectral curve in this fashion requires a well controlled heat source. The CO_2 laser is a particularly well adapted heat source for silica glass in general and optical fibers in particular. The coefficient of absorption of 10 μm radiation is so high for silica that most of the power is absorbed within the first 10-20 μm thick layer. Also, silica can tolerate very rapid heating and cooling cycles because its coefficient of thermal expansion ([illegible]) is so low. Fiber optic splicing or cleaving and the fabrication of long period gratings are just a few examples of the many uses of CO_2 lasers in this field (4,5). The lasers themselves are cheap, robust and require very little maintenance.

Assuming then that the temperature profile along the grating can be controlled, FIG. 2 outlines the general annealing-trimming process. The $s(\lambda)$ and E_d spectra are added to the error spectra to calculate the required temperature profile, assuming a fix length heating cycle. The process is repeated until the required tolerances on the error function is reached. FIG. 2 does not show the initial calibration phase where two rapid uniform temperature anneals are performed from which initial values for $s(\lambda)$ and E_d are calculated.

FIG. 3 is a schematic of the annealing-trimming station. All components and measurements are computer controlled. An important hardware component for this particular system is the XY-scanner which allows fast and precise positioning of the laser beam along the chirped FBG. During the annealing-trimming steps, the laser beam is constantly scanned at high speed along the chirped FBG. The required precise temperature profile is obtained through a position-modulated technique which essentially controls the laser fluence along the grating by locally varying the scan speed. Alternately, the scan speed could be fixed and the laser fluence could be modified as a function of its position along the grating. Another possibility is to have the scan speed and laser fluence fixed and to add a rapid oscillating movement of the laser beam in the axis perpendicular to the fiber axis. Ajusting the amplitude of this perpendicular oscillation as the beam moves along the fiber would also have the same effect as varying the local laser fluence.

Each new gain flattening filter to be processed is roughly positioned in place by the operator and connected to the optical spectrum analyzer (OSA). A low-temperature heat-scan technique is then used to automatically calibrate the position of the grating. A similar technique can be used to estimate the grating strength and thus cladding mode losses along the chirped FBG.

In short, the software does all data processing and commands a temperature profile, and the hardware provides the mean to create the temperature profile along the chirped FBG. Of course, in practice, in order to achieve repeatable and precise trimming, the algorithm must take into account many other factors such as: cladding mode losses, frequency response of the scanner, finite laser beam width and fiber thermal response. Nevertheless, because of the multi-step approach and the self-adapting algorithm, the process is very robust.

FIG. 4 illustrates a specific example of the results obtainable with the present invention. In this case, a chirped FBG gain flattening filter was submitted to an arbitrary temperature profile to simulate corrections in 4 distinct zones. Learning from previous annealing steps, the software was able to accurately predict the resulting change in the gain flattening filter spectra; even smaller

details like the tail of rightmost zone and the overlap of the two middle zones were correctly calculated.

The following example illustrates the overall process. FIG. 5 shows the evolution of the error function from the moment the gain flattening filter arrived at the station and for several of the 10 seconds trimming scans. In this particular case, the initial error is unusually large because the gain flattening filter was intentionally overwritten to illustrate the capability of the process. Theoretically, the trimming could be accomplished in a single step. However, because over-trimming is difficult to correct, a multi-step approach is preferred.

FIG. 6 illustrates the final results, showing the initial gain flattening filter, the target and final curve. The top graph of FIG. 6 shows the residual error function along with the high-frequency component of the gain flattening filter spectra just after UV-writing. The final error function is approximately ±0.1 dB, almost totally limited by the original high-frequency component. In this case, the target error function was ±0.15 dB.

In some special cases, reaching the required target in a specific region along the chirped FBG could lead to over-correction to nearby regions because of heat diffusion. These regions can be automatically detected by the software and corrected by using a very fast on-off scanning process that limits heat diffusion.

Some additional features are relatively easy to implement. For example, the station can be instructed to not only consider the error function of the gain flattening filter being process but all other previous error functions of the same series. This type of batch processing can further reduce the overall systematic error of cascaded gain flattening filters. It can also be envisioned that a single profile at the UV-writing station could fit many end-profiles, simplifying the manufacturing process.

The preferred embodiment described here pertains more specifically to chirped FBG gain flattening filters but the main technique and apparatus could also be applied to other complex FBG filters.

Numerous modifications could be made to the embodiments above without departing from the intended scope of the present invention.

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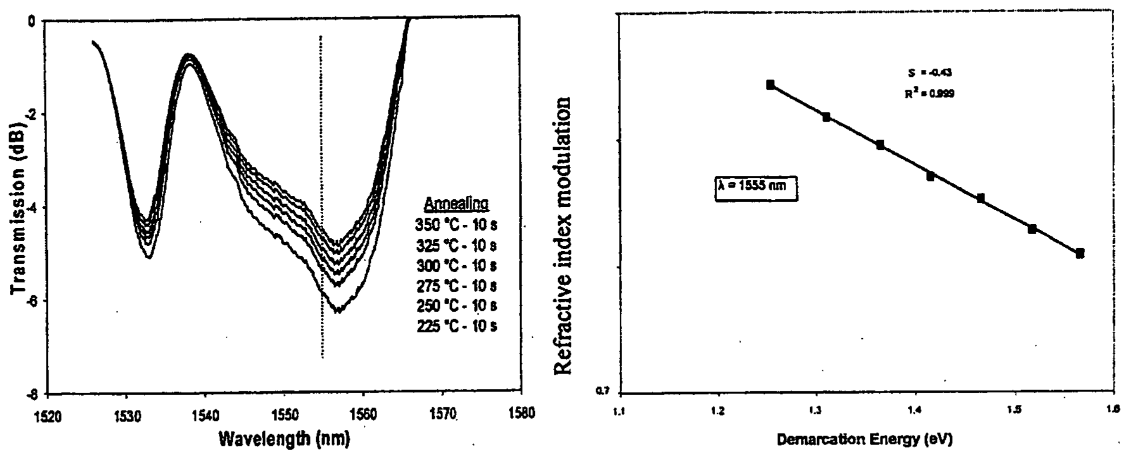

Fig. 1: The graph on the right represent isochronal annealing curves for a typical CFBG-GFF. At any given wavelength, the behavior is well represented by a master curve (right).

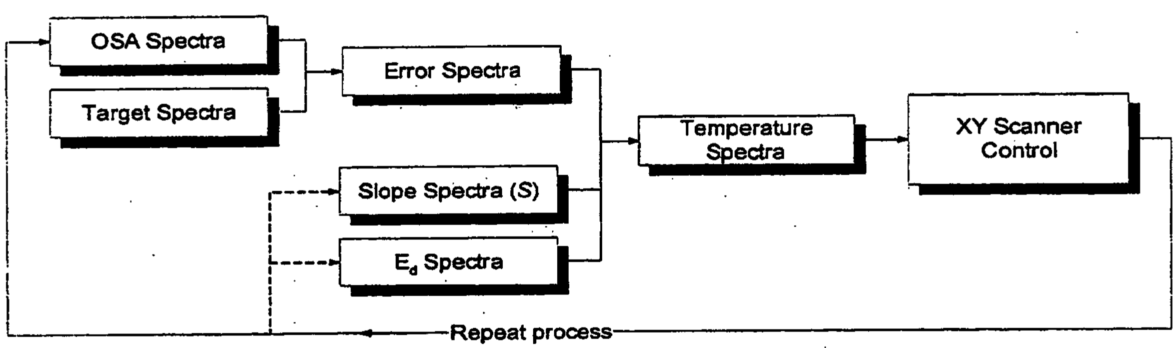

Fig. 2: Outline of the algorithm used in correcting the GFF.

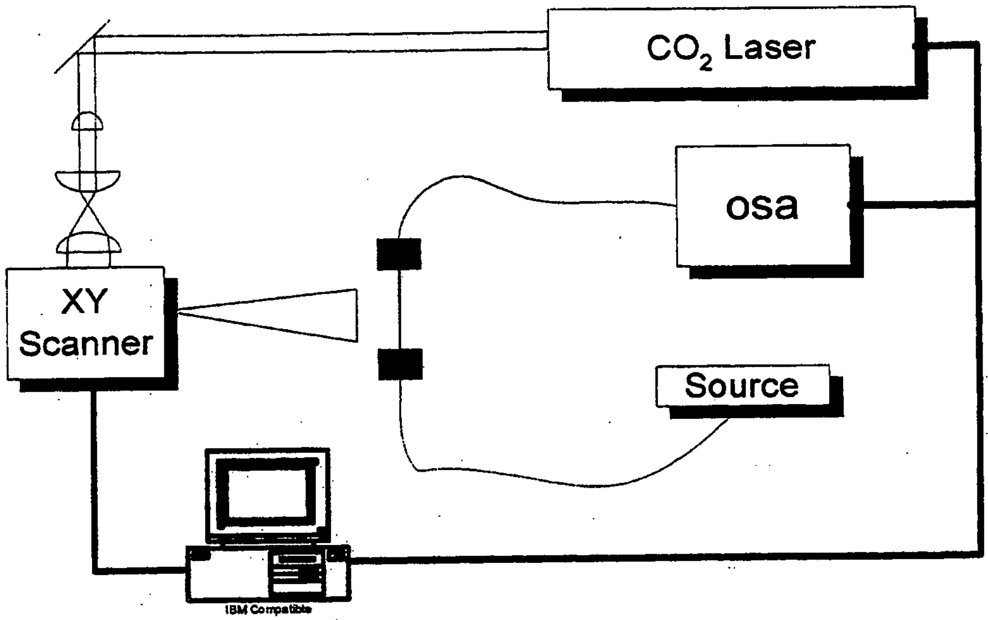

Fig. 3: Schematic of the annealing-trimming station.

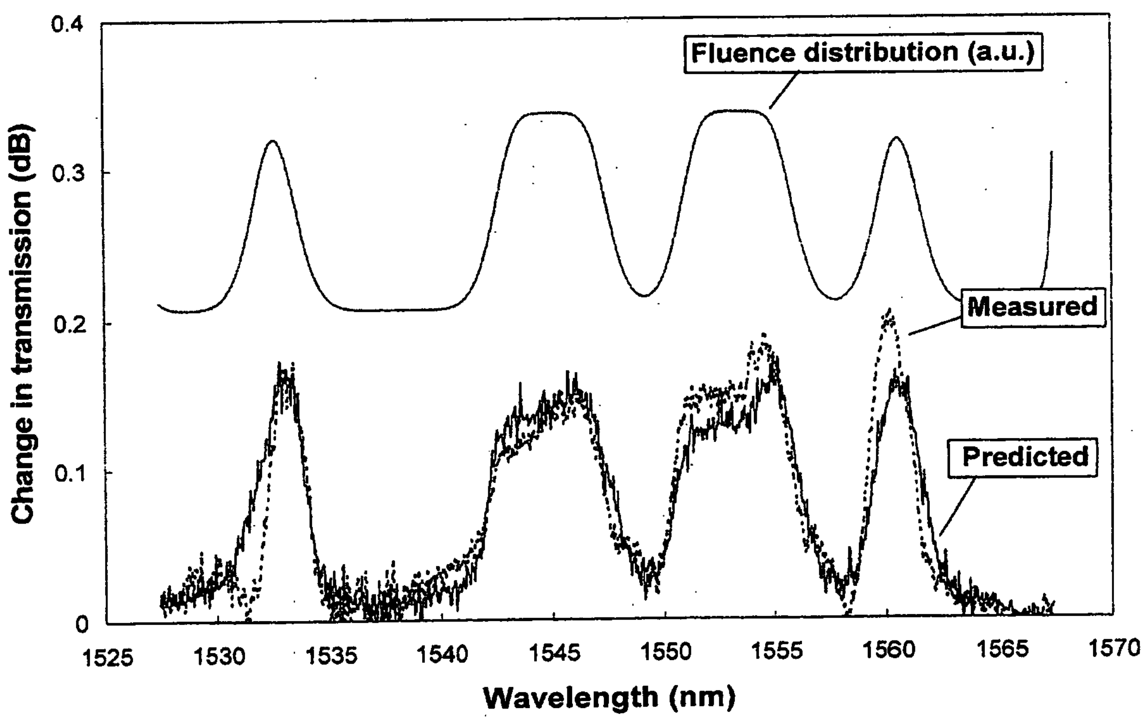

Fig. 4: Top curve shows the applied laser fluence (temperature) profile. Bottom curves are the measured and predicted changes in the GFF transmission spectra.

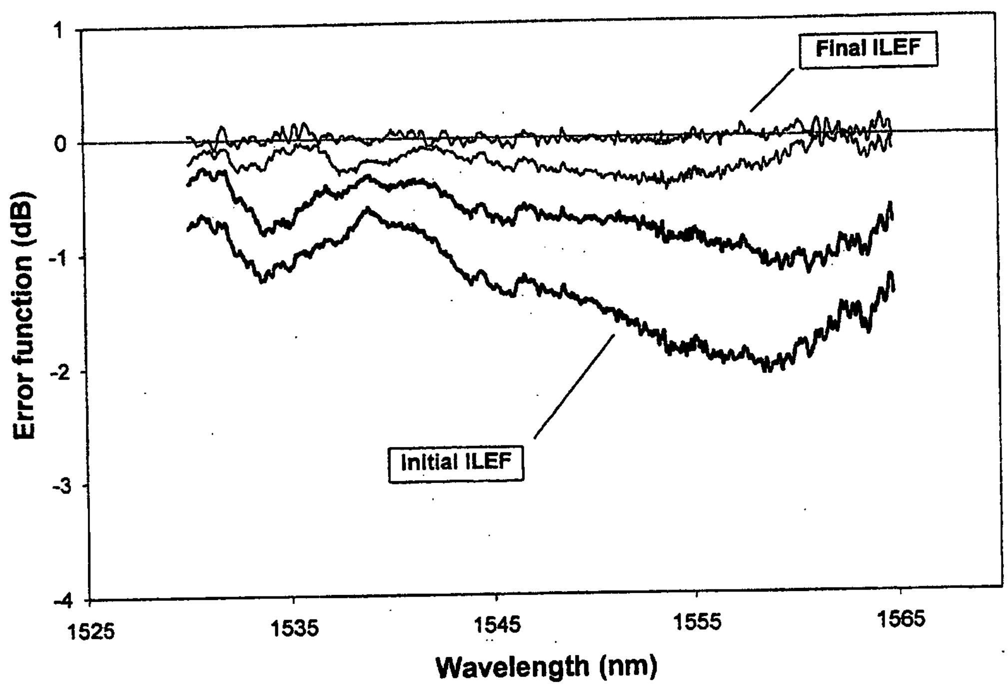

Fig. 5: Evolution of the error function from start (bottom trace) to finish (top trace). Each trace represent a 10 seconds profiled annealing.

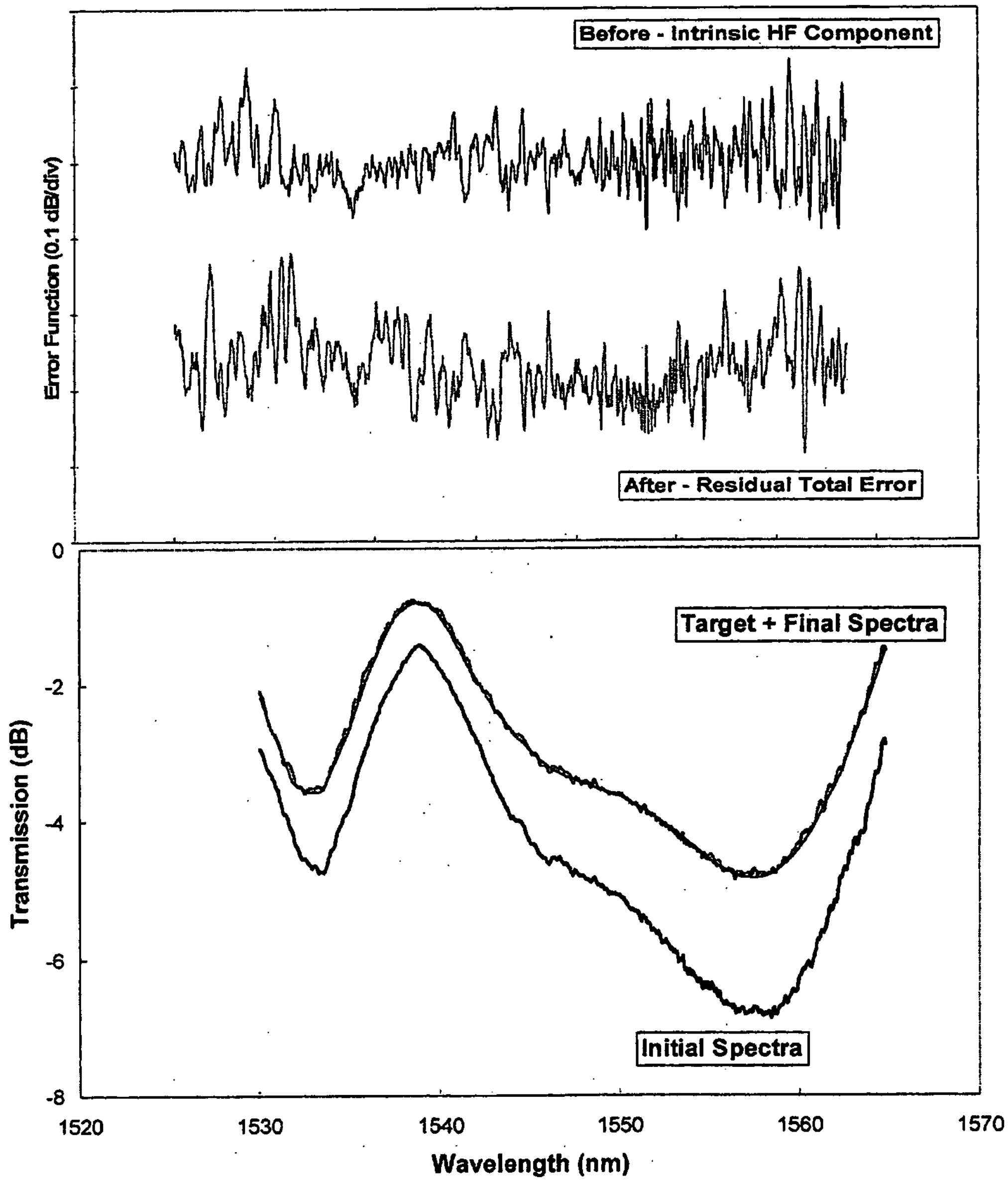

Fig. 6: Bottom graph shows the initial GFF spectra and the final spectra along with the target. The top graph shows the residual error (lower trace) along with the isolated higher-frequency noise of the initial spectra (top trace).